295

NO

MSC INTERNAL NOTE NO. 66-EG-21

PROJECT APOLLO

# HANDHELD LEM OPTICAL RANGEFINDERS FOR LEM-CSM LUNAR RENDEZVOUS


Prepared by: Indulis Saulietis
Indulis Saulietis

Prepared by: G. L. Roland
George L. Roland

Approved by: Paul E. Ebersole
Paul E. Ebersole
Chief, Guidance Development Branch

Approved: R. G. Chilton
Robert G. Chilton
Deputy Chief, Guidance and
Control Division





NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MANNED SPACECRAFT CENTER

HOUSTON, TEXAS

April 12, 1966

## STATEMENT OF PROBLEM

At the present time, the LEM G&C system contains no range and range rate capability in event of complete failure of either radar or optical navigational equipment except for MSFN. MSFN data is probably not reliable for the critical terminal phase of the rendezvous. An investigation of backup capability in the form of a simple handheld optical device was therefore initiated.

Two devices appear to offer accuracy good enough to give range and range rate data to the LEM pilot during the last 20 n. mi. of rendezvous. The first of these is a completely passive device which measures the angular size of the CSM and therefore its range. The second device is a doublt slit interference device requiring a CSM-mounted light source.

Double Rotating Wedge Rangefinders - Two devices of the first type mentioned above were evaluated for accuracy and repeatibility of range readout. The first of these was a NASA constructed device shown on Figure 1. It consists of a Questar catadioptric telescope with a dual aperture plate in front of the correcting lens. The line of sight through one of the apertures can be (continuously) deviated from 0 to about 120 arc seconds by means of two prism wedges, one fixed and the other rotatable.

To obtain the range to a known size object, the procedure is as shown on Figure 2. A range readout is obtained when the two images are just tangent. This device gave quite good accuracy to a range of about 15 miles, assuming a 15' diameter CSM.

An 800' long range was measured and readings taken by several observers using 40 and 80X magnifications. Figure 3 shows a plot of the wedge rotation readouts obtained at various ranges. The two curves represent the most probable error boundaries (i.e., most readings will fall between the two curves) and the vertical cross lines represent the maximum errors obtained.

The second device was a prototype diastimeter constructed by Kollsman Instruments. It operates on a principle similar to the NASA device except that it starts with a preset line of sight deviation and finds the wedge rotation necessary to bring the two images into tangency. Figure 4 is an optical schematic of the Kollsman device and Figure 5 illustrates its ranging geometry.

The Kollsman device was calibrated in range (feet) for a 12' diameter object. A 1/25 scale range was surveyed with markers at 400' intervals to 4,800'. Since the device itself has a 2" baseline, exact scaling down of the target (to 12/25 foot diameter) was not possible. Using the formula supplied for wedge angle at image tangency:

$$\theta = \sin^{-1}\left\{1 - \left[\frac{\sin^{-1}\left(\frac{D_T - B}{d}\right) - \delta_0}{\delta_1}\right]\right\}$$

$\Theta$ = wedge rotation from 0

$D_T$ = target diameter

B = instrument baseline

d = range to target

$_o$ = initial LOS deviation (constant)
= 24.5 arc sec

$_1$ = maximum wedge deviation (constant)
= 1° 59' 45"

An expression can be obtained which gives the diameter of the scale target giving range readings correct to 1/25th scale:

$$D_{TS} = \frac{D_T + 24B}{25}$$

$D_{TS}$ = diameter of simulated target

$D_T$ = CSM diameter

It was felt that 10X magnification was about the maximum that could be used in a handheld rangefinder. The device was attached to 10X 50 binoculars and range data was taken at night on a circular target simulating a 12' object. The data obtained is shown on Table I. Figure 6 is the mean error obtained versus true range. Figure 7 shows the effect of learning on the accuracy obtained.

It can be seen on Figure 6 that the errors exceed ±10% after 38,000'. On Figure 7, a noticeable bias toward high readings can be seen. This is probably because it is difficult at 10X magnification to tell whether the images are tangent or not so the tendency of the observer is to bring them closer together so they will appear to touch, but in actuality are overlapping giving a range indication greater than expected.

Both observers had little experience with the device as is evident from Figure 7. The second set of observations yielded more accurate data for each observer.

Suggestions for improving the Kollsman device are:

a. Provide finer adjustment mechanism for the wedges. The present 6:1 ratio is still too fast.

b. Expand the scale with divisions every 1,000'. Scales should not be marked 5,000 - 7,500 - 10,000 etc. as this is confusing.

c. Redesign the readout magnifier so as to eliminate parallax errors. These can be as much as 5% of the total reading.

d. Put a light on the readout so it can be used at night.

e. Increase friction in adjusting mechanism.

Double Slit Interference Rangefinder - The general layout of the double slit method of measuring the angular diameter of a distant source is shown in Figure 8. A large objective lens of 1 to 2 meters focal length is employed with a pair of narrow slits in front whose distances from center are continuously adjustable. The real image of the diffraction pattern may be examined with a high power eyepiece.

If light from a slit source or a straight lamp filament is viewed through the above apparatus, interference fringes will be observed in the diffraction pattern and are particularly bright and clear near the center. If the slit separation is continuously decreased from an initial wide separation, the interference fringes will periodically disappear and reappear. The criteria(1) for these disappearances is given by:

$$\alpha = \frac{n\lambda}{d}$$

where $\alpha$ is the angular diameter of the slit source as measured from the double slits, $n$ is a positive interger, $\lambda$ is the wavelength of light being used (5,500A if white), and d is the separation between the double slits. For a circular source, this may be shown(1) to be:

$$\alpha = \frac{1.22\,n\lambda}{d}$$

If one continues to decrease the slit separation, a point will be reached where the fringes will no longer disappear no matter how close the slits are brought together. At this point if one increases the distance (d) until the first order disappearance occurs, he has the relationship (for a circular source):

$$\alpha = 1.22\lambda/d$$

or letting $\alpha = a/\ell$

where a = the diameter of the source and $\ell$ = the distance to the source then:

$$\ell = ad/1.22\,\lambda$$

This method was tested in the Guidance and Control Division high bay area by measuring the distance to a lamp filament of known diameter. The maximum error incurred on thirty readings was 1.5%. The average error was less than 1%. The method as described, however, relies on human decision and eyeball resolution, both of which are poor. The actual point of disappearance is difficult to observe in a laboratory and probably impossible in a moving vehicle. It is believed, however, that a relatively simple mechanization of the apparatus would produce a compact, workable, and highly accurate range finding device. A simplified block diagram of the intended method is shown in Figure 9.

A seemingly excellent telescope for the apparatus would be a Questar which has a 54" focal length, a large (3 1/2") objective, and is folded into a small package weighing about two pounds. The eyepiece would be replaced by a microscope objective or equivalent. A small solid state detector with a narrow field of view could be made to scan the image by means of a small oscillating mirror such as the positor mirror from a horizon scanner. A small set of logic then, which examines the AC component of the output signal, could control a motor which drives the slits and results in a very tight limit cycle about the slit separation of interest.

The method, as applicable to the Apollo mission, would require a small, bright monochromatic light source on the CSM oriented in the same spacecraft angular position as the SCT. Since the assumption has been made that the astronaut in the CSM will know approximately where the LEM is and will be looking for it, it is reasonable to assume that the astronauts in the LEM would get a "full" view of the light source. Error in the reading would vary as the cosine of CSM misorientation about the roll axis which is very small for angles less than 10° or so. A narrow band interference filter would be employed to keep other scattered light from the CSM from affecting the measurement.

A conception of the final version might be as in Figure 10. A small, wide angle telescope with a small circular reticle in the center, depicting the field of view of the measuring optics, could be mounted on top of the main telescope. A head rest and eye cup (now shown) could be provided for stability. If the device was battery operated and energized by a button on the side, the astronaut would merely have to acquire the CSM in the reticle, push the button and hold for two or three seconds, release the button, and read range directly from a vernier on the slit apparatus.

The total package should weigh less than five pounds and have the approximate dimensions shown in Figure 3.

The mechanization described with the exception of the slits being manually operated has been examined in the laboratory. The waveforms are very distinct and repeatable and should be easily discriminated in a mechanized version.

## WORK IN PROGRESS

A dynamic simulation of the LEM-CSM rendezvous to 1/25 scale is currently being set up. Timed range data will be obtained with both the Kollsman device and the double slit interference device, and compared with the externally measured range-range rate history of the target. This comparison should help decide whether the device offers any backup capability to the lunar rendezvous.

## REFERENCE

1. Jenkins, F. A. and H. E. White, "Fundamentals of Optics", McGraw-Hill Book Company, Inc., New York, 1957, pp 321-322.

TABLE I
DATA OBTAINED APRIL 6, 1966 FOR KOLLSMAN DIASTIMETER

| True Range | Observer I (I. Saulietis) | | Observer II (D. Peterson) | |
|---|---|---|---|---|
| | First Try | Second Try | First Try | Second Try |
| 10,000 | 8,100 | 10,000 | 11,000 | 10,000 |
| 20,000 | 20,000 | 17,500 | 19,500 | 20,000 |
| 30,000 | 31,000 | 30,500 | 27,000 | 30,000 |
| 40,000 | 50,000 | 46,000 | 40,000 | 43,000 |
| 50,000 | 70,000 | 55,000 | 50,000 | 50,000 |
| 60,000 | 75,000 | 69,000 | 72,000 | 68,000 |
| 70,000 | 89,000 | 85,000 | 55,000 | 85,000 |

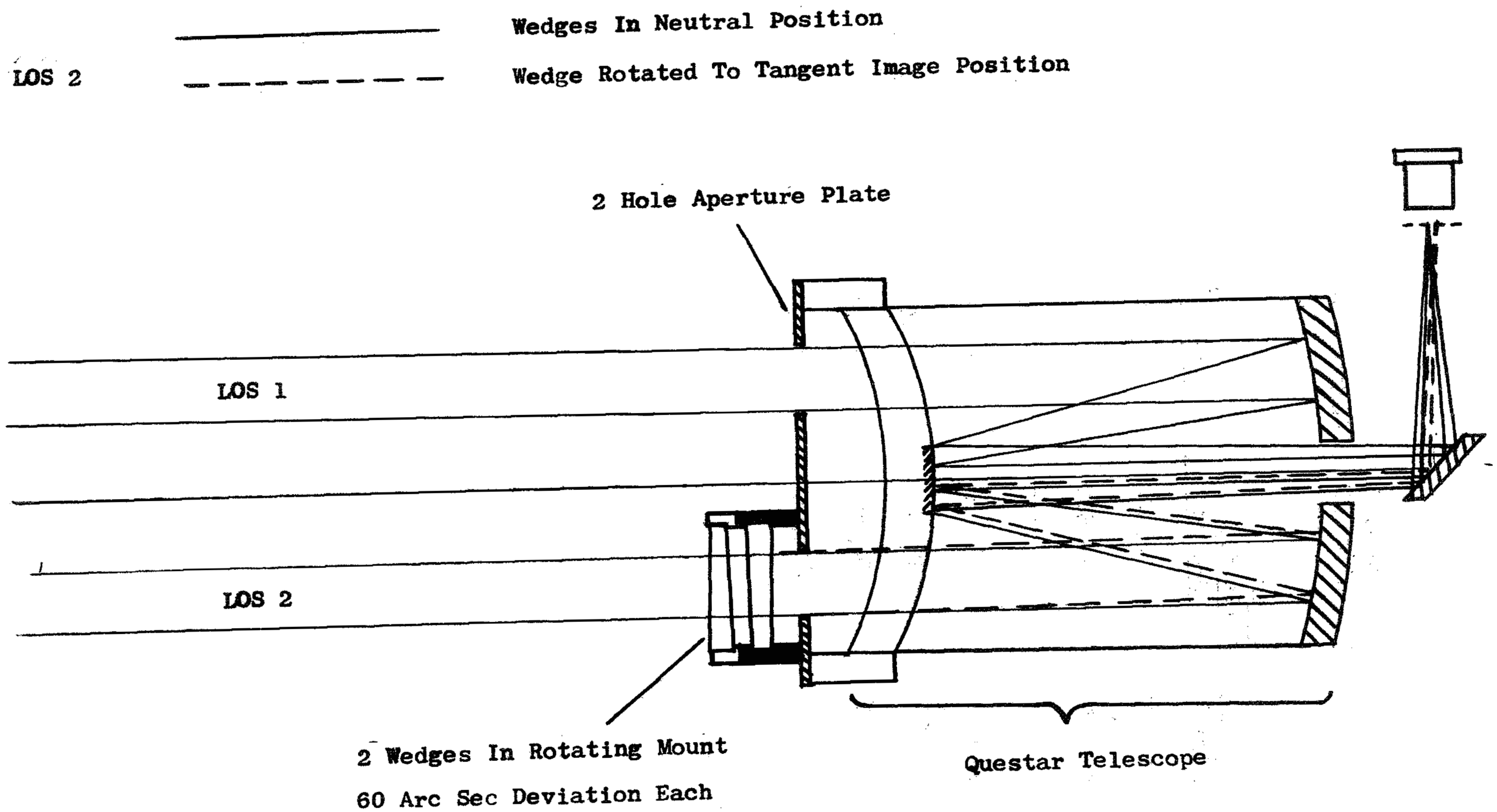


Figure 1

ROTATING DOUBLE WEDGE RANGEFINDER

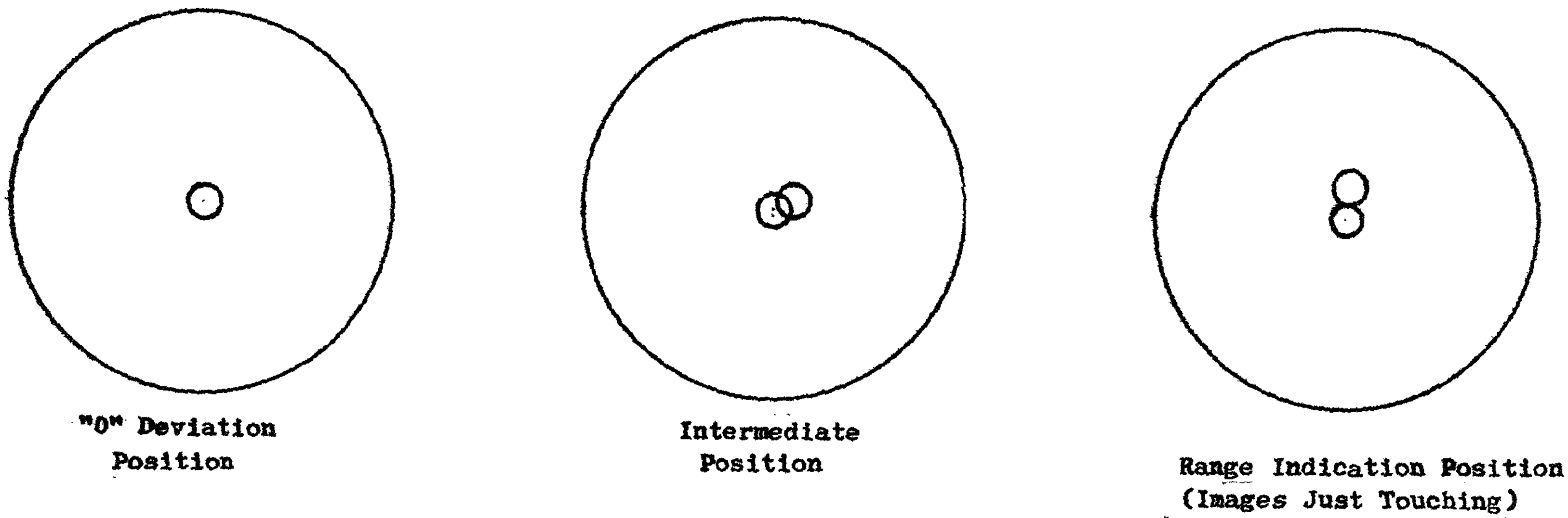


Figure 2

APPEARANCE OF IMAGES FOR CERTAIN SETTINGS OF DOUBLE WEDGE RANGEFINDER

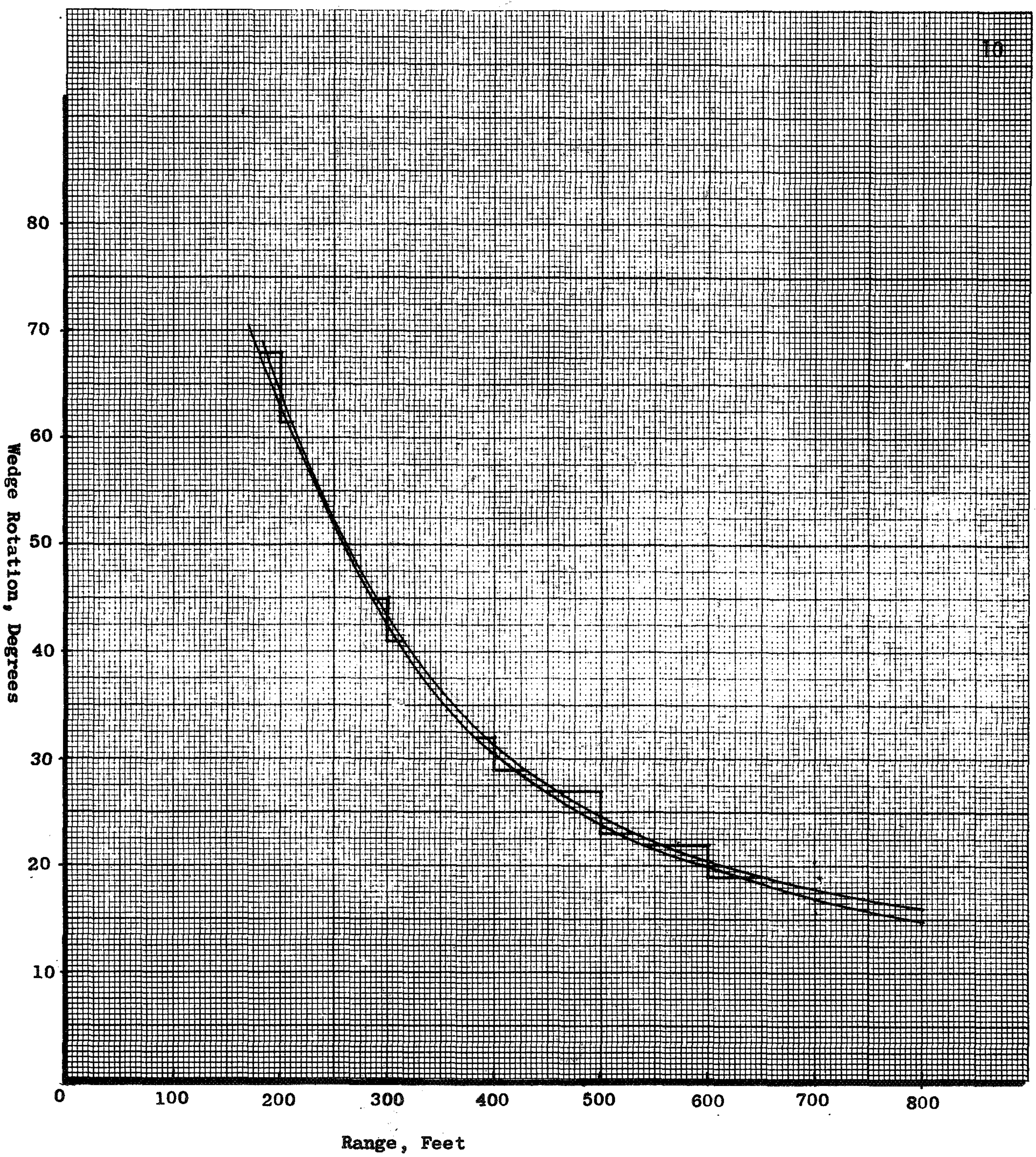


**Figure 3**

DATA PLOT FOR ROTATION WEDGE RANGEFINDER

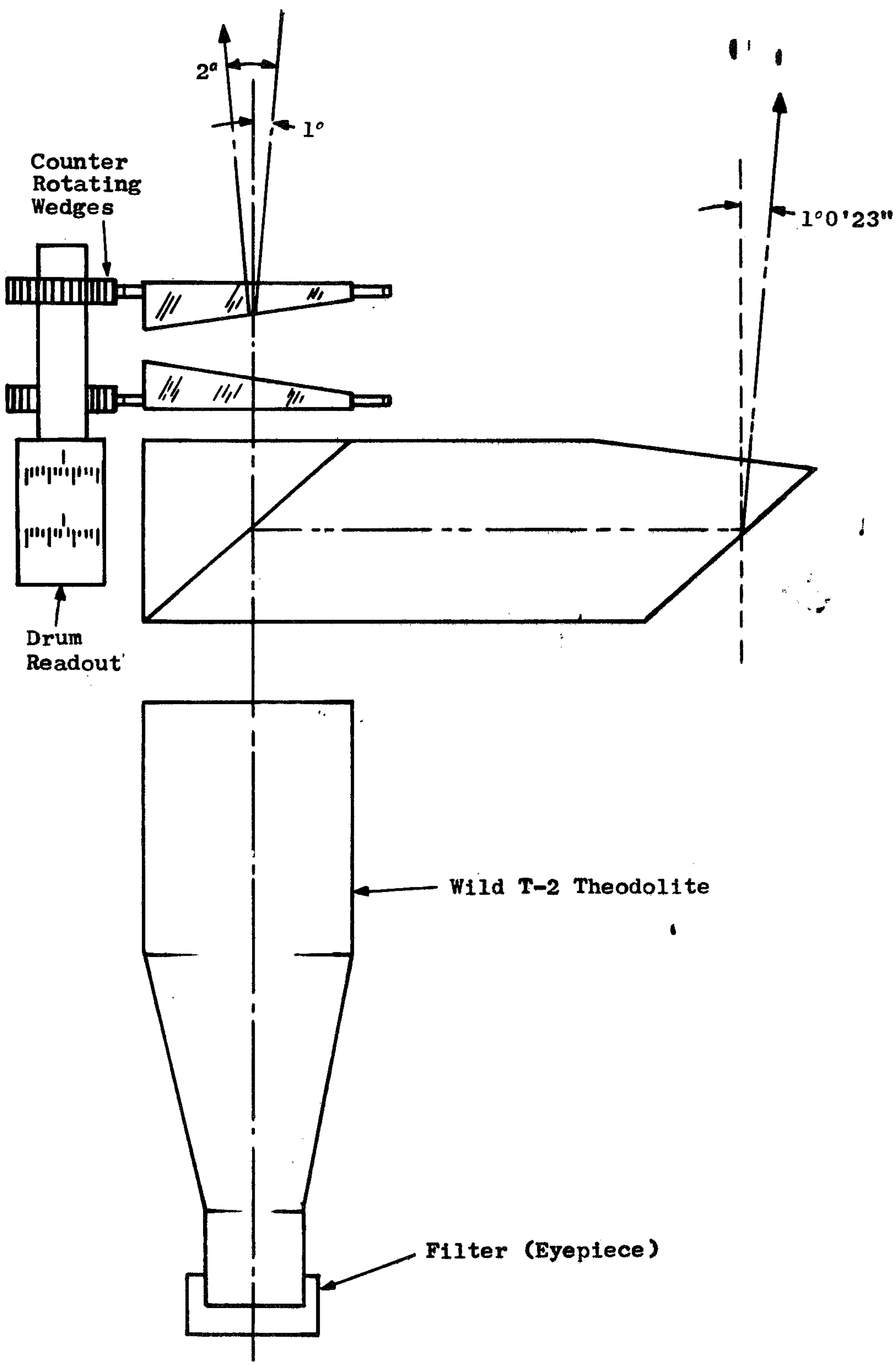


Figure 4

DIASTIMETER OPTICAL SCHEMATIC

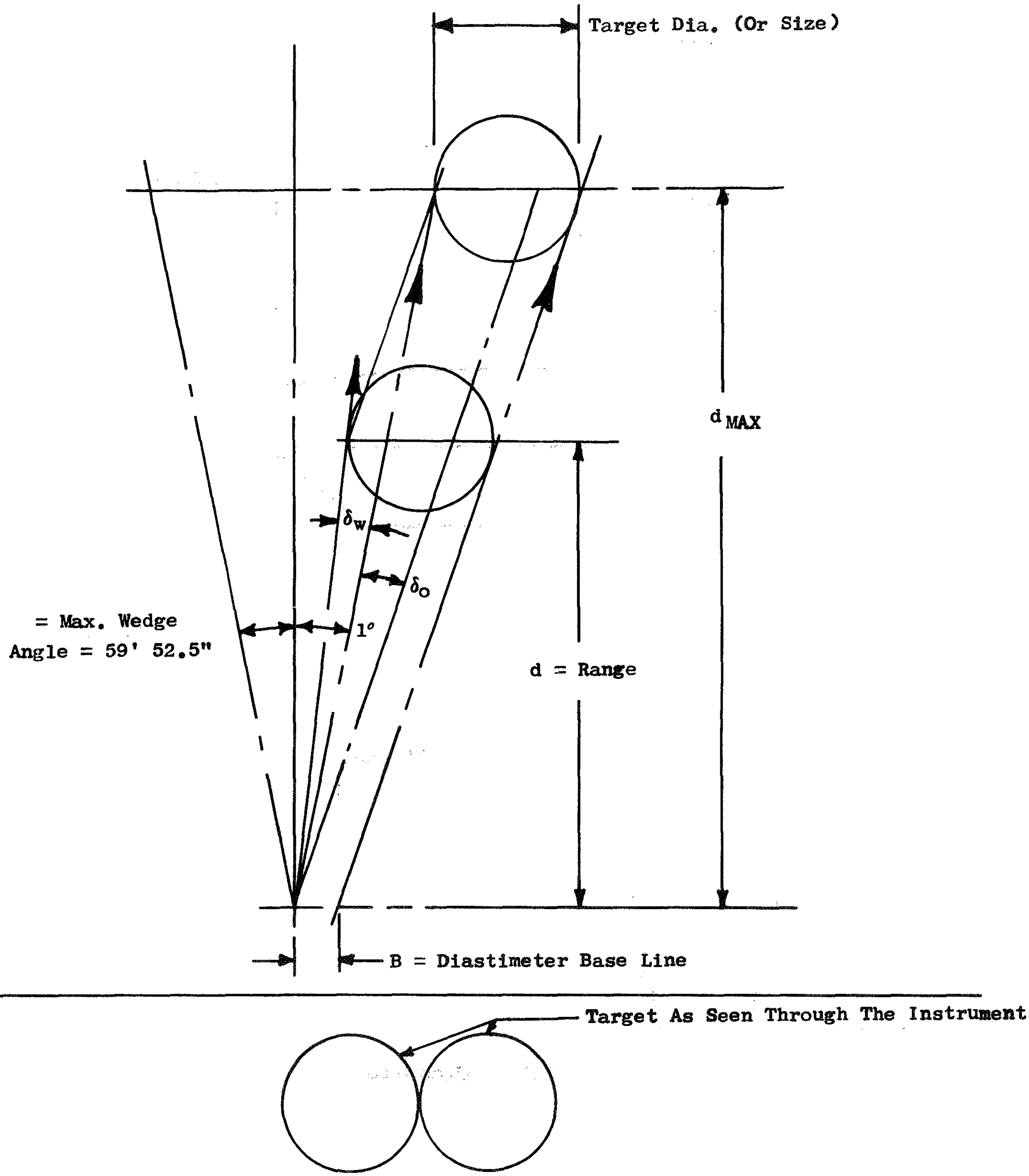


**Figure 5**

KOLLSMAN DIASTIMETER RANGING SCHEMATIC

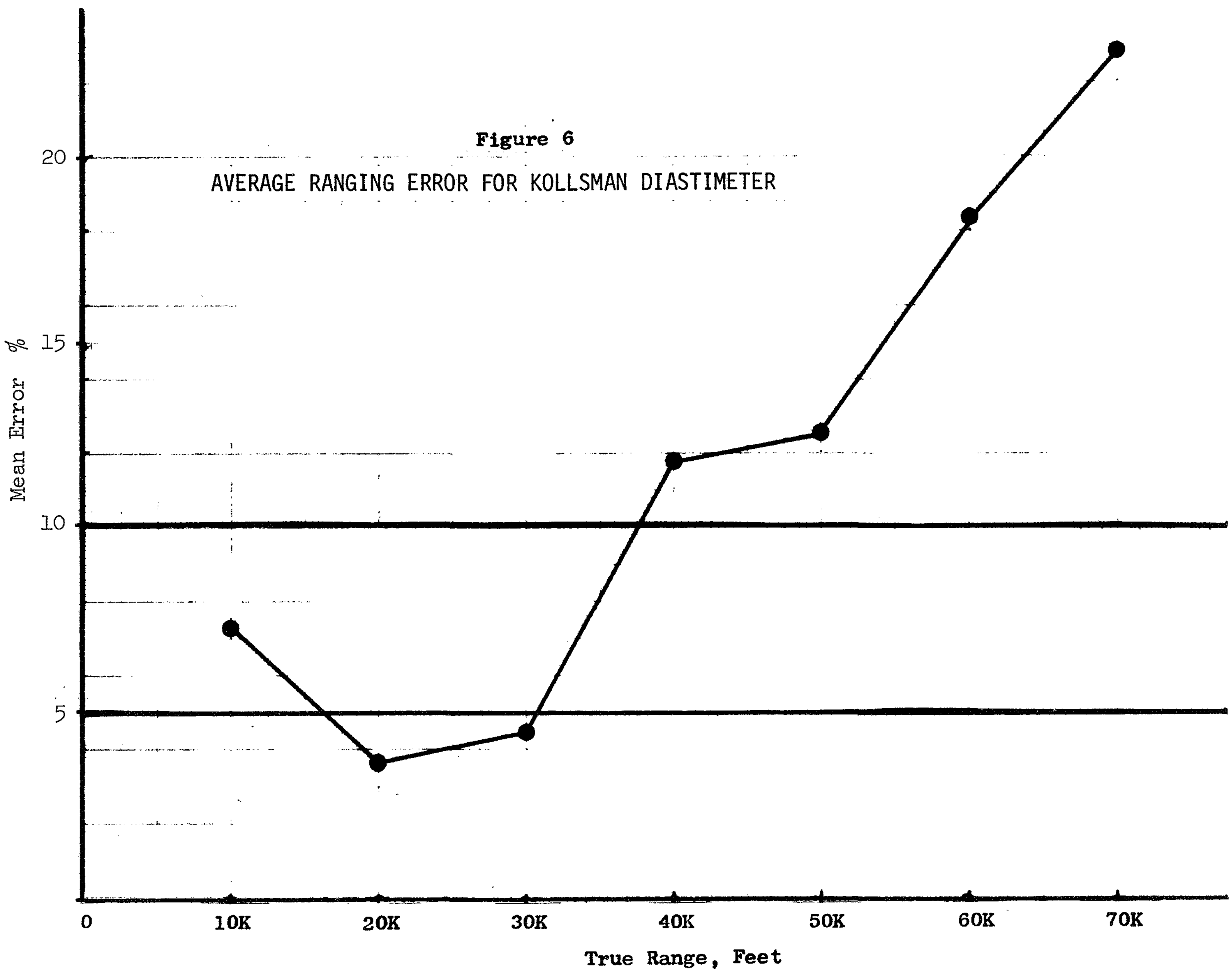


**Figure 6**

AVERAGE RANGING ERROR FOR KOLLSMAN DIASTIMETER

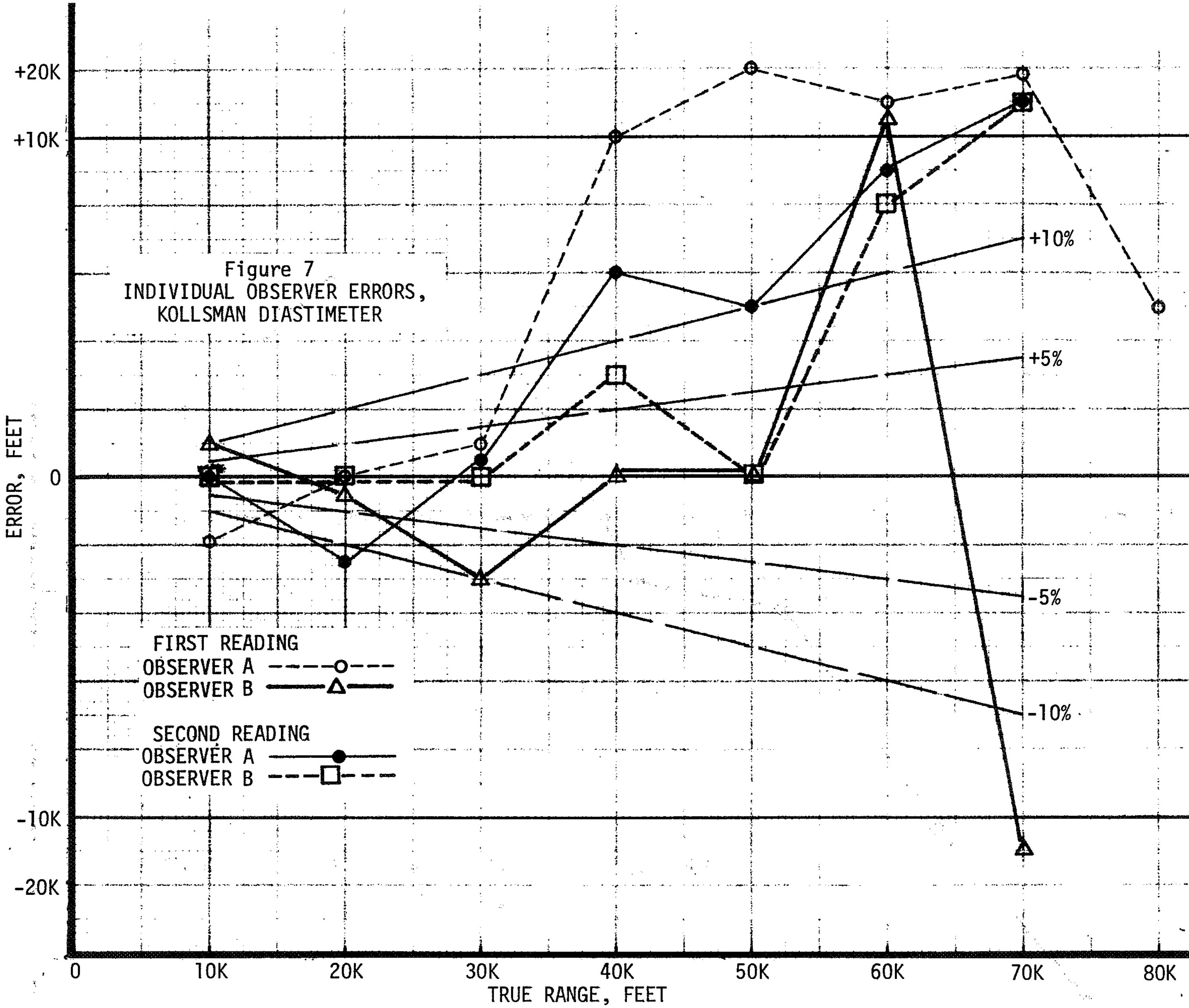


Figure 7
INDIVIDUAL OBSERVER ERRORS,
KOLLSMAN DIASTIMETER

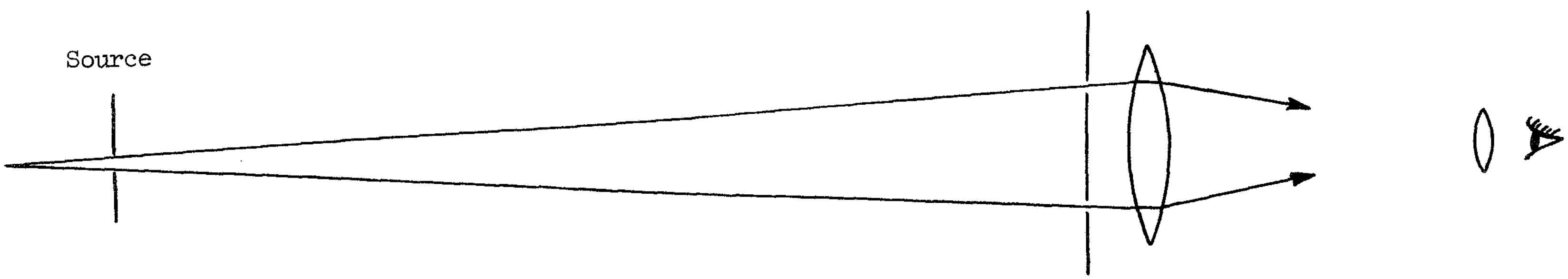


Figure 8
ARRANGEMENT OF THE DOUBLE SLIT EXPERIMENT

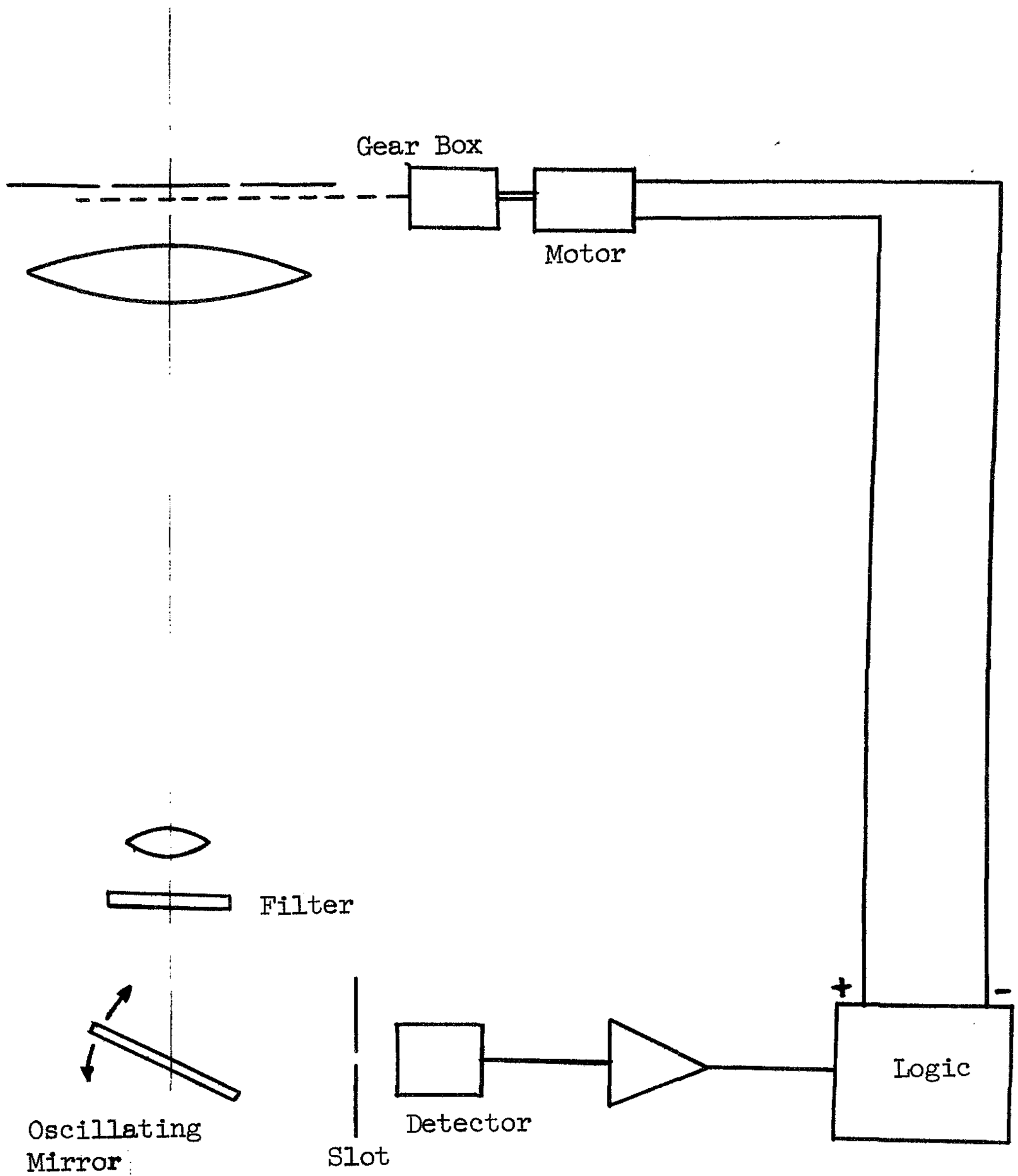


Figure 9
MECHANIZATION OF THE DOUBLE SLIT APPARATUS

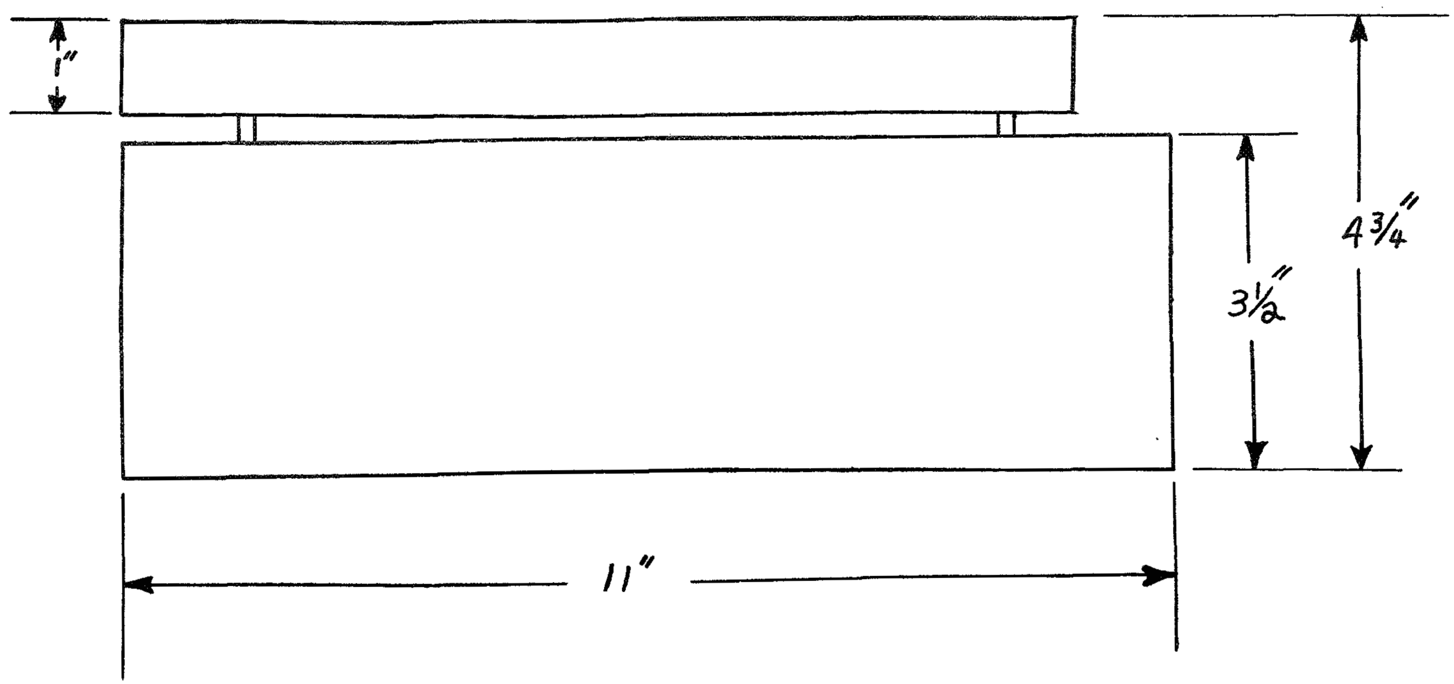


Figure 10
APPROXIMATE DIMENSIONS OF THE FINAL MECHANIZED CONFIGURATION